

**Automated Vertical Clearance
Measurement During Photolog Operations**

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**September 2000
Revised November 2000**

Report No. 2220-F-2000-4

**Connecticut Department of Transportation
Bureau of Engineering and Highway Operations
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Technical Report Documentation Page

1. Report No. 2220-F-2000-4	2. Government Accession No.	3. Recipients Catalog No.	
4. Title and Subtitle Automated Vertical Clearance Measurement During Photolog Operations		5. Report Date September 2000	
		6. Performing Organization Code SPR-2220	
7. Author(s) Robert G. Lauzon, Ph.D., P.E.	8. Performing Organization Report No. SPR-2220		
9. Performing Organization Name and Address Connecticut Department of Transportation Division of Research 280 West Street Rocky Hill, CT 06067-3502		10. Work Unit No. (TRIS)	
		11. Contract or Grant No. CT Study No. SPR-2220	
		13. Type of Report and Period Covered Final Report 7/98 to 9/00	
12. Sponsoring Agency Name and Address Connecticut Department of Transportation 2800 Berlin Turnpike Newington, CT 06131-7546		14. Sponsoring Agency Code SPR-2220	
		15. Supplementary Notes A study conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration	
16. Abstract <p>The Connecticut Department of Transportation uses two digital-based photolog vans to collect four different sets of roadway images as well as 40 different types of alphanumeric data, including vertical cross slope and horizontal geometry. A request for overhead clearance information from Department personnel involved with the permitting of oversize/overweight vehicles, and the discovery of a prototype device developed by the FHWA, prompted a proposal to incorporate this type of data collection into the existing photolog activities.</p> <p>This report summarizes the testing of the prototype device, the assembly and use of a new device, and the results of limited field testing. Data for several bridges and cantilevered overhead sign structures are presented. Observations are made as to the comparison of the data to clearance diagrams created by bridge safety inspectors. Conclusions based on these observations are presented and recommendations are made for further study.</p>			
17. Key Words Vertical Underclearance, Bridges, Oversize/Overheight Vehicles, Vehicle Permits, Photologging		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA. 22161	
19. Security Classif. (Of this report) Unclassified	20. Security Classif.(Of this page) Unclassified	21. No. of Pages 29	20. Price

Form DOT F 1700.7 (8-72)

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METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL WHEN YOU KNOW MULTIPLY BY TO FIND SYMBOL

LENGTH

in	inches	254	millimeters	cm
ft	feet	304.8	millimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

in ²	square inches	254	square millimeters	mm ²
ft ²	square feet	0.092903	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	Acres	0.4	hectares	ha

MASS (weight)

oz	ounces	2.5	grams	g
lb	pounds	0.453592	kilograms	kg
	short tons (2000 lb.)	0.9	Megagrams	mg

VOLUME

tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
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SYMBOL WHEN YOU KNOW MULTIPLY BY TO FIND SYMBOL

LENGTH

mm	millimeters	0.03937	inches	in
cm	centimeters	0.3937	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi

AREA

cm ²	square millimeters	0.00155	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	

MASS (weight)

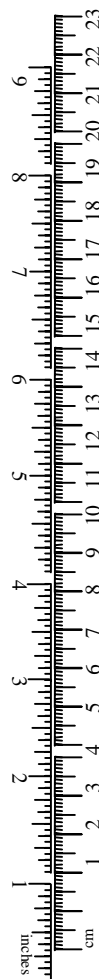
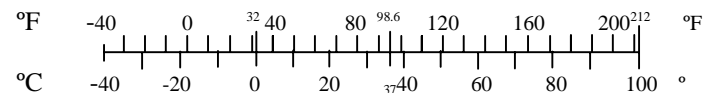
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	Megagrams (1000 kg)	1.1	short tons	

VOLUME

ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	36	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
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APPROXIMATE CONVERSIONS FROM METRIC MEASURES

List of Abbreviations and Acronyms

Abs	Absolute value
A/D	Analog to Digital
Avg	Average
BS&E	Bridge Safety and Evaluation
ConnDOT	Connecticut Department of Transportation
DAQ	Data Acquisition
Delta	Difference between the average distance measured by the inspector and the average distance measured by the device developed in this study.
Department	Connecticut Department of Transportation
FHWA	Federal Highway Administration
ft	feet
GPIB	General Purpose Interface Bus
GPS	Global Positioning System
Hz	Hertz
in.	Inches
KHz	Kilohertz
lft	Left
mA	milliAmp
Max.	Maximum
MFD	Microfarad
Min.	Minimum
mph	Miles per hour
mW	milliWatt
NB	Northbound
NBI	National Bridge Inventory
PC	Personal Computer
PCMCIA	Personal Computer Memory Card International Association
Rsquare	Coefficient of Correlation
rt	Right
Rte.	Route
SB	Southbound
VERMS	Vertical measurement System

Automated Vertical Clearance Measurement During Photolog Operations



Texas Department of Transportation

Connecticut Department of Transportation

Figure 1. Overhead Problems

Introduction

During the course of this study, the above photos were discovered and brought to mind that the problem of tall vehicle vs. low bridge is one that has been around for a while and apparently isn't going away. While the results of this study will not eliminate these incidents, the investigators do intend to provide a method that can provide more information regarding overhead clearances than has been available before, and hopefully reduce the frequency of these incidents.

Background and Significance

ConnDOT is a leader in the use of state-of-the-art technology for the inventory of State maintained highways. Two digital-based data collection systems are currently used by the Department to collect four different sets of roadway images as well as over 40 different types of alphanumeric data including information on roadway profile geometry

and surface condition. These systems reside in full-sized vans, commonly referred to as photolog vans, that are driven by ConnDOT personnel over the state highway network at highway speed (48 mph max.) on an annual basis. See Figure 2. Data is generally collected during the summer months on sunny, dry days so that the images collected can be used for pavement condition assessment. The philosophy behind this method is that all data is collected during a single pass of a vehicle. These digital-based systems are modular in design and are capable of future expansion to collect other types of linear-referenced data.



Figure 2. ConnDOT's Data Collection Vans

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FHWA's Office of Engineering Research and Development developed a prototype device for the automated measurement of the vertical distance to overhead objects from a moving vehicle. The device utilizes a laser to measure the distance to an overhead object at speeds of up to 60 mph. The results of limited initial testing of this device appeared promising. The FHWA personnel involved in this project demonstrated the device to Department personnel and were receptive to the loan of the prototype and development of a multi-laser device by ConnDOT personnel.

Currently ConnDOT's BS&E unit is responsible for determining the overhead clearances for bridges and overhead sign supports in Connecticut. For bridges, this is done during the normal inspection, every two years. Overhead clearance diagrams showing lane locations under the bridge are produced during each in-depth inspection every ten years. Vertical clearances are measured manually using a fiberglass rod at the edge of each lane, and are noted on the diagram. This measurement requires traffic protection, which can be substantial on Interstates and in urban areas. The minimum vertical clearance at a single location is also determined in the field and noted. This value is then input to the NBI database as Item # 54. Item #10 in the NBI database, the minimum clearance for a ten-foot width of pavement under the bridge, is also determined in the field and noted on the diagram. A ten-foot width that produces the maximum clearance is used. Subsequent normal inspections require the inspectors to verify each of these clearances. If they have changed, the clearance diagram is generally updated, as is the NBI database.

For sign structures, the Department has just begun a comprehensive Sign Structure Inventory and Inspection Program. Initial field inspections, which were

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completed in 1996, provided clearance diagrams and the clearance information used in this study. Sign structures will be inspected every four years, with clearance information updated as required.

Problem Statement

Accurate minimum overhead clearances for all bridges and overhead Sign structures are required for the issuance of oversize load permits. These measurements must also be taken more often, and in a safer manner. These data are critical to the Department's responsibility for routing of oversized vehicles. Poor or inaccurate data can damage vehicles and highway structures as well as the reputation of the Department to produce efficient routes for these vehicles. Overly conservative routing inhibits economic activity and provides the impetus for unauthorized route modifications.

Objectives

The objectives of the study are: to determine if the device developed by FHWA is reliable and accurate enough to determine vertical clearances under overhead objects; to develop a multi-laser device with three sensors instead of one and test such a device to determine if it can be used to simultaneously measure three locations accurately on an overhead object; and, draft a technical specification for the integration of such a device into the existing Department data collection vehicles.

Prototype Testing

The prototype device, developed by personnel at the Saxton Electronics Laboratory at FHWA's Turner Fairbank Highway Research Center, was loaned to ConnDOT Research personnel. The device consisted of two major components: a single laser diode-based measurement sensor and a pulse generator that attached to the lug nuts

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of a vehicle wheel. The sensor was mounted in a plastic tube approximately 4 in. in diameter and 18 in. long. A lightweight aluminum frame, that attached to any flat surface with suction cups, held the tube in a vertical position. The pulse generator was used to trigger the sensor. The data acquisition component was custom built by FHWA personnel and provided a user with the ability to power the device on and off, trigger data collection for each overhead object and download the data to a laptop PC. The specification for this device is not available. Based on the known width of a beam measured with the device, the apparent horizontal resolution was on the order of 3 to 4 inches.

Department personnel mounted the device on a vehicle from the research motor pool and collected data for three days. Preliminary analysis of these data showed good repeatability and reasonable results. Unfortunately on the fourth day, the pulse generator broke free of the lug nuts of the vehicle at 50 mph and was destroyed. Since the device as built was triggered by the pulse generator, further data collection was not possible without replacement of that component. Given that the purchasing process would delay the project for many months, the output collected to date was reviewed further and determined to support continuation of the project. A replacement pulse generator was eventually purchased and transferred to the FHWA.

Next Generation Device

Using the prototype as a guide, Department personnel purchased and integrated the following components into a functional device.

Component	Cost	Comment
Distance Sensor (3)	\$12,525.00	20mW/current loop output/optical filter
Power Supply	\$140.00	12 volt to 6 volt
Roof Rack	\$400.00	off the shelf with modifications
Sensor Housing	\$50.00	fabricated
Wiring/Incidentals	\$200.00	Terminal Strip/Cable/Wire
Laptop	\$2,500.00	
PCMCIA Interface	\$654.00	GPB 8/16 channel A/D Converter
Total	\$16,469.00	

Table 1. Component Cost

Given the bad experience with the pulse generator, the cost of such a device, and the existence of linear reference data available with the Department's photolog vans, this component was eliminated in this study. It is anticipated that a date/time stamp or other parameter will effectively link the vertical clearance and linear reference data sets together. The latter includes detailed speed information and will provide reasonable information on horizontal distance traveled. Discussions with personnel who would use the measurements revealed that they were more concerned with accurate (± 3 in.) vertical clearance data than knowing precisely the width of the overhead object.

By choosing a sampling frequency that ensures that the underside of each typical girder is measured at least once, any variation in vertical clearance due to the width of the bridge will be accounted for. A higher sampling frequency that measures the underside of each typical girder several times will account for variation in vertical clearance due to the width of the girder, which is less likely to be a concern.

Once assembled and bench-tested in the laboratory, the device was installed and field tested on the same fleet vehicle used for the prototype testing. As stated earlier, because photolog vans are dedicated to data collection during the summer months, they were not used for the development of this device. The vehicle installation is shown in Figure 3.



Figure 3. Vehicle Rack and Sensor Housings

Hardware Setup

The distance-measuring sensors output a current from 4 to 20 milliamps that is proportional to the distance measured (0 to 650 in.). This current is calibrated to account for temperature and signal strength. This current is updated once per sample at a rate that can be selected from 0.1 Hz to 770 Hz and is constant between samples. For this study, the three sample rates used were 50, 100 and 500 Hz. These rates were chosen because 100 Hz is the upper limit recommended by the sensor manufacturer to limit thermal noise, 50 Hz is half that, and 500 Hz represents a horizontal sample rate @ 50 mph of 1.76 in. This resolution is fine enough to detect overhead sign structures and narrow structures.

Also, per the recommendation of the sensor manufacturer, the current is measured using a simple circuit consisting of a small resistor in parallel with a capacitor for each sensor. A 470 ($\pm 5\%$) ohm resistor and a 1 MFD capacitor. The voltage across the resistor was read by a multi-channel data acquisition system composed of a laptop computer with a PCMCIA card that provides analog to digital conversion. The rate at which the voltage is

sampled is also selectable from 0.1 to 1,000 Hz. The software provided with the PCMCIA card was used to trigger the data collection, set the sample rate, name a file for each overhead object and store those files on the laptop.

Data Collection

A segment of Interstate 91 in Rocky Hill/Wethersfield, Connecticut, was chosen to evaluate the sensor and data acquisition equipment. This segment was chosen because it includes many overpasses and overhead sign structures as indicated in Table 2, and is convenient to the ConnDOT Research facility. A manual trigger was used to trigger data collection for each overhead object. It is anticipated that user interface software could be developed that would automatically poll a sensor dedicated to identifying upcoming objects, triggering the measurement sensors, and storing the data as appropriate.

Route	Van Speed (mph)	Overhead Structure	Type	Member(s)	Paint condition
I-91 NB	50	West Street	Steel/Conc. Deck	10 girders	Poor
I-91 NB & SB	50	CT Rte 160	Steel/Conc. Deck	5 girders	Poor
I-91 NB & SB	50	Gilbert Ave.	Steel/Conc. Deck	6 girders	New
I-91 NB	50	Exit 24 Sign	Cantilever	Round tube	Very good
I-91 NB	50	Exit 24 Sign	Cantilever	Round tube	Very good
I-91 NB & SB	50	Orchard Street	Steel/Conc. Deck	6 girders	New
I-91 NB	50	Exit 24 Sign	Cantilever	Round tube	Very good
CT 99 NB	35	I-91 NB & SB	Steel/Conc. Deck	11 girders	Poor
I-91 SB	50	Exit 23 Sign	Cantilever	Round tube	Very good
I-91 SB	50	Exit 23 Sign	Cantilever	Round tube	Very good
I-91 SB	50	Exit 23 Sign	Cantilever	Round tube	Very good
I-91 SB	50	Exit 23 Sign	Cantilever	Round tube	Very good

Table 2. Overhead Structures Used in Study

Results

The raw data output from the DAQ system consisted of three columns of numbers that represented the voltage read from each sensor at each sample. These numbers were

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then converted into physical distances, using the ranges provided by the sensor manufacturer, and factors provided by the DAQ system manufacturer. Noteworthy at this point, was the sensitivity of the resulting distance to the value of resistor used to calculate the voltage. For a difference of ± 1 ohm, the distance varies approximately ± 0.044 ft or 0.5 in. To increase the accuracy of the distance measured, a high precision resistor ($\pm 0.1\%$) should be used. In the case where there was nothing overhead, the voltages were close to zero and a default distance of 51 ft was artificially inserted.

The data for a representative bridge at the 500 Hz collection rate are shown in the left half of Table 3. Readings that were repetitive could be easily attributed to the underside of the parapet, underside of girder, underside of deck, underside of girder, etc. Some of the single measurements, such as 5.069558, that appeared at the outside edges of the bridges were obviously false readings. These are thought to be caused by reflected sunlight and/or the slanted surfaces that normally exist at the edge of the concrete parapet. In order to eliminate them, it was decided to define a repeated measurement as one that did not change more than 0.2 ft from one to the next, and only retain those measurements. Therefore, any measurement that wasn't effectively repeated with the next measurement was deleted. This process resulted in data free of false readings as shown in the right half of Table 3. Such processing was not possible with the sign measurements because there were no repeated measurements. For sign structures, all measurements were evaluated.

To develop a clearance from the road surface, the vertical distance from the sensor face to the floor was measured with the vehicle stationary and added to the data represented in Table 3. This distance, the height of the sensor, can obviously vary as the

van travels down the road, due to the suspension of the vehicle, wind, etc. The photolog vans are continually measuring the vertical distance between the four corners of their platform and the roadway surface for transverse- and horizontal-profile development. For vertical clearance purposes, a real-time, height-of-sensor measurement could be used to increase the accuracy of the vertical clearance measurement.

Distance measured by each sensor (ft)			Repeated distances measured by each sensor (ft)		
Right	Middle	Left	Right	Middle	Left
51	51	51	51	51	51
51	51	51		51	51
11.87212	51	51		51	51
13.31723	51	51	13.31723	51	51
13.42297	51	51	13.42297	51	51
13.45821	51	51	13.45821		51
13.45821	5.069558	51	13.45821		51
13.45821	11.87212	51			51
10.6385	12.40082	51		12.40082	51
9.052407	12.47131	51	9.052407	12.47131	51
8.911421	12.50656	51	8.911421	12.50656	
8.876175	12.50656	11.13195	8.876175	12.50656	
8.911421	12.50656	12.04835	8.911421		12.04835
8.876175	10.95571	12.11885	8.876175		12.11885
8.911421	10.18029	12.11885		10.18029	12.11885
12.57705	10.07455	12.15409		10.07455	12.15409
13.00001	10.1098	12.15409	13.00001	10.1098	
13.0705	10.1098	11.76638	13.0705	10.1098	
13.0705	10.1098	11.48441	13.0705	10.1098	11.48441
13.03526	10.1098	11.44917	13.03526		11.44917
13.03526	11.90737	11.44917		11.90737	11.44917
13.38772	12.0836	11.41392	13.38772	12.0836	11.41392
13.56395	12.11885	11.44917	13.56395	12.11885	11.44917
13.5992	12.11885	11.44917	13.5992	12.11885	
13.5992	12.11885	10.99096	13.5992	12.11885	10.99096
13.5992	12.0836	10.92047	13.5992		10.92047

Table 3. Processed Clearance Data

The next step in the data processing was to determine the absolute minimum distance measured by each sensor, which was done using the repeated data. These minimum distances were compared to the distance shown on the most recent clearance

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diagram available for each structure. The date that these diagrams were first produced and the distances at the left and right edge of lane in which the research vehicle traveled are shown on Tables 4 through 6. It is important to note that the location or girder of the minimum clearance for a sensor does not necessarily coincide with the location or girder of the other sensors. The intention is to compare the accuracy of the measured minimums, regardless of location, for the 50, 100 and 500 Hz sensor-sampling rate respectively.

Some observations are;

- The differences (Delta) between the average clearances that were measured by the device and by bridge inspectors diminish as the sensor-sampling rate increases. This is demonstrated by the average delta calculated for 50, 100, and 500 Hz that are 2.38, 0.32, and 0.25, respectively. The difference is also not biased above or below the measured values.
- The improved results with a 500 Hz. sampling rate appears to minimize the thermal noise concern that was mentioned by the manufacturer with rates above 100 Hz. It must be noted however, that the sensors were powered for relatively short periods during this study. Network-level data collection may cause this issue to be revisited.
- The coefficient of correlation (Rsquare) between the left measured clearance and Delta for the 50, 100, and 500 Hz sensor-sampling rate is 0.66, 0.14 and 0.001, respectively. This indicates the low sampling rate is a significant cause of inaccurate results.

- The average Delta is 0.19 ft (2.3 in.) for information collected @ 500 Hz within the last five years.
- The condition of the paint on the bridge did not appear to influence the accuracy of the measurement. This is illustrated in the results for the first and third bridges where the paint condition was poor and new respectively, yet delta was the same.
- The measurements made at the slowest vehicle speed at bridges 1448 and 1449, had the greatest accuracy regardless of the sensor sampling rate. This may foretell a need for slower vehicle speeds at bridges with minimal clearances where very accurate measurements are required.
- Of the 17 instances where sign structures were measured with the device, only one failed to produce any results.
- As with bridges, the accuracy of the sign measurements apparently improves with increased sampling rate.

Data Collected @ 50 Hz Sensor sampling rate										
Route	Bridge (#)	Minimum Measured Clearance (feet)						Delta (ft)	R square (l _{left} ,Delta)	
		Inspection			Device					
		Date	Left	Right	Left	Middle	Right	Abs(Avg(l)-Avg(D))	0.667515523	
I-91 NB	West Street (3162)	2/9/99	16.5	16.75	18.33	17.83	18.42	1.57		
I-91 NB	Rte 160 (3164)	9/27/95	18.5	19.33	23.00	20.00	23.00	3.09		
I-91 NB	Gilbert Ave. (3031)	6/6/97	17.17	17.25	21.00	20.00	21.75	3.71		
I-91 NB	Orchard Street (3025)	3/19/93	17.33	17.42	20.92	20.58	20.08	3.15		
Rte 99 NB	I-91 (1448 & 1449)	4/13/99	14.33	14.42	14.33	14.33	14.33	0.04		
I-91 SB	Orchard Street (3025)	3/19/93	16.67	16.42	18.92	18.25	18.50	2.01		
I-91 SB	Gilbert Ave. (3031)	6/6/97	16.42	16.25	16.33	22.08	16.92	2.11		
I-91 SB	Rte 160 (3163)	9/27/95	20.08	18.5	20.50	23.50	24.00	3.38		
			Clearance						2.38	Avg all bridges
									2.32	Avg bridges inspected in last 5 years
	Sign (#)	Date	Sign	Support	Min.	Max.	Notes	Abs(Face-Min.)		
I-91 NB	Exit 24 - 1 mile (21482)	4/12/96	18.8	19.0	16.00	NA	lft only	2.80		
I-91 NB	Exit 24 - 1/2 mile (21483)	4/12/96	19.65	20.8	19.08	NA	rt only	0.57		
I-91 NB	Exit 24 - arrow (21484)	4/12/96	19.78	22.2	17.75	18.83	all	2.03		
I-91 SB	Exit 23 - 1 mile (21466)	4/13/96	18.41	19.0	17.17	17.67	mid & rt	1.24		
I-91 SB	Exit 24 - 1/2 mile (21467)	4/13/96	18.275	19.4	18.92	NA	rt only	0.65	Average	
I-91 SB	Exit 24 - arrow (21468)	4/13/96	18.87	19.4	13.92	17.08	all	4.95	2.04	

Table 4. Data for 50 Hz Sensor Sampling Rate

Data Collected @ 100 Hz Sensor sampling rate									
Route	Bridge (#)	Minimum Measured Clearance (feet)						Delta (feet)	R square (Left,Delta)
		Inspection			Device				
		Date	Left	Right	Left	Middle	Right	Abs(Avg(I)-Avg(D))	0.13956274
I-91 NB	West Street (3162)	2/9/99	16.5	16.75	17.25	17.08	17.00	0.48	
I-91 NB	Rte 160 (3164)	9/27/95	18.5	19.33	18.70	20.25	20.17	0.79	
I-91 NB	Gilbert Ave. (3031)	6/6/97	17.17	17.25	17.08	17.08	17.25	0.07	
I-91 NB	Orchard Street (3025)	3/19/93	17.33	17.42	17.58	18.00	18.17	0.54	
Rte 99 NB	I-91 (1448 & 1449)	4/13/99	14.33	14.42	14.25	14.30	14.30	0.09	
I-91 SB	Orchard Street (3025)	3/19/93	16.67	16.42	16.83	16.75	16.58	0.17	
I-91 SB	Gilbert Ave. (3031)	6/6/97	16.42	16.25	16.17	16.17	16.08	0.20	
I-91 SB	Rte 160 (3163)	9/27/95	20.08	18.5	19.00	19.25	18.92	0.23	
			Clearance					0.32	Avg.all bridges
								0.31	Avg. bridges inspected in last 5 years
	Sign (#)	Date	Sign	Support	Min.	Max.	Notes	Abs(Sign-Min.)	
I-91 NB	Exit 24 - 1 mile (21482)	4/12/96	18.8	19.0	NA	NA	no data pts	NA	
I-91 NB	Exit 24 - 1/2 mile (21483)	4/12/96	19.65	20.8	19.25	19.8	lft & rt	0.40	
I-91 NB	Exit 24 - arrow (21484)	4/12/96	19.78	22.2	18.42	18.5	mid & lft	1.36	
I-91 SB	Exit 23 - 1 mile (21466)	4/13/96	18.41	19.0	18.5	NA	mid only	0.09	
I-91 SB	Exit 24 - 1/2 mile (21467)	4/13/96	18.275	19.4	18.5	NA	rt only	0.23	Average
I-91 SB	Exit 24 - arrow (21468)	4/13/96	18.87	19.4	18	19.5	mid & rt only	0.87	0.59

Table 5. Data for 100 Hz Sensor Sampling Rate

Data Collected @ 500 Hz Sensor sampling rate										
Route	Bridge (#)	Minimum Measured Clearance (feet)						Delta (feet) Abs(Avg(I)-Avg(D))	R square (Ileft,Delta) 0.000961958	
		Inspection (I)			Device (D)					
		Date	Left	Right	Left	Middle	Right			
I-91 NB	West Street (3162)	2/9/99	16.5	16.75	16.60	17.13	17.26	0.37		
I-91 NB	Rte 160 (3164)	9/27/95	18.5	19.33	19.24	17.72	20.11	0.11		
I-91 NB	Gilbert Ave. (3031)	6/6/97	17.17	17.25	17.97	17.75	16.94	0.34		
I-91 NB	Orchard Street (3025)	3/19/93	17.33	17.42	17.17	18.36	18.11	0.50		
Rte 99 NB	I-91 (1448 & 1449)	4/13/99	14.33	14.42	14.32	14.34	14.31	0.05		
I-91 SB	Orchard Street (3025)	3/19/93	16.67	16.42	17.07	17.14	16.54	0.37		
I-91 SB	Gilbert Ave. (3031)	6/6/97	16.42	16.25	17.00	16.22	16.15	0.12		
I-91 SB	Rte 160 (3163)	9/27/95	20.08	18.5	19.47	18.51	19.46	0.14		
			Clearance						0.25	Avg.all bridges
									0.19	Avg. bridges inspected in last 5 years
	Sign (#)	Date	Sign	Support	Min.	Max.	Notes	Abs(Face-Min.)		
I-91 NB	Exit 24 - 1 mile (21482)	4/12/96	18.8	19.0	NA	NA	system not triggered	NA		
I-91 NB	Exit 24 - 1/2 mile (21483)	4/12/96	19.65	20.8	19.42	20.22	mid & rt only	0.23		
I-91 NB	Exit 24 - arrow (21484)	4/12/96	19.78	22.2	19.42	20.22	mid & lft only	0.36		
I-91 SB	Exit 23 - 1 mile (21466)	4/13/96	18.41	19.0	18.93	19.61	mid & lft only	0.52		
I-91 SB	Exit 24 - 1/2 mile (21467)	4/13/96	18.275	19.4	17.42	19.19	all	0.85	Average	

Table 6. Data for 500 Hz Sensor Sampling Rate

Conclusions

- 1.) The type of sensor is well suited for the measurement of the vertical under clearance of overhead highway structures. This is evident from the fact that all bridges, and 16 of 17 sign structures, were measured in some form during each pass of the vehicle no matter what the sampling rate was. It is also supported by the lack of correlation between the condition of the paint (reflectivity) on a bridge and the apparent accuracy of the device measurement.
- 2.) A minimum sampling rate of 500 Hz is required for a vehicle speed of 50 mph. For a vehicle speed of approximately 35 mph, a slower sampling rate may be adequate.
- 3.) The use of a manual trigger is adequate for a small number of overhead structures; however, the collection of network-level data will require an automated trigger.
- 4.) Sign structures may not be adequately measured at 50 mph vehicle speed regardless of sampling rate, due to their narrow profiles.
- 5.) There are no perceived obstacles to installing the three-sensor system onto the Department's photolog vehicles, although this was beyond the scope of work of this project. However integrating the system with the existing data-collection platform will require some additional development.

Recommendations

- 1.) A software interface should be developed to control the sensors and record the data in a format that will be useable on a network level. In conjunction, an automated trigger should be developed using a dedicated sensor to predetermine the existence of an overhead structure in time to trigger the measurement sensors.
- 2.) More data should be collected to determine the accuracy of the sensors on various types of bridges, and sign structures at high sample rates (500 Hz and higher). Different types of data processing methods should be explored.
- 3.) Algorithms should be developed to determine the cross slope and grade of the overhead object with respect to a vehicle passing underneath it. This should be integrated with the cross slope and grade of the highway to produce a virtual opening. The opening should be evaluated to determine where minimum or maximum clearances are.
- 4.) Means to integrate existing photolog vehicle-platform data into the results should be done to increase the accuracy of the measurement and determine what the deviation from true-vertical is and how that affects the results.
- 5.) Further study should include determining the feasibility of developing this device as an independent device that could be mounted on a BS&E vehicle for multi-lane measurement of vertical clearance on a bridge-by-bridge basis.
- 6.) Further study should also include the refinement of the draft specification to reflect the experience of additional data collection in recommendation #2 and

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address specific integration issues so that data can be collected as part of the annual photolog inventory of state-maintained highways.

Appendix A

DRAFT SPECIFICATION FOR AN

AUTOMATED VERTICAL CLEARANCE DEVICE

DESCRIPTION: Work under this item shall consist of furnishing, installing, and integrating a laser-diode based vertical measurement system (VERMS) to determine the minimum vertical distance under overhead objects located on state-maintained highways into existing data collection (photolog) vans owned by the Department of Transportation in accordance with these specifications. It shall be possible to operate VERMS independently of other data acquisition systems in the photolog van and vice-versa.

GENERAL:

- Before any work begins, a meeting shall be held between the Vendor and the Department of Transportation (Department) photolog representatives to discuss the existing photolog vehicles and any proposed modifications to these vehicles in the course of providing this system.
- All data generated by the system shall become the sole property of the Department. Use by others is prohibited, unless written authorization is provided by the Department.
- All equipment furnished with this system will be new and in current manufacture.
- Upon installation the Vendor must demonstrate the full functionality and operation of VERMS while the van is stationary and while it is collecting data at normal highway speeds. All existing systems on the vehicle must be completely unaffected by the operation of the system. The Department reserves the right to determine if a system is affected or not.
- Any openings or holes made in the existing vehicle must be made waterproof and remain waterproof for the life of the vehicle. If at any time the waterproofing fails, the Vendor is responsible for the full cost of repair of the seal and any equipment that is damaged as a result of the leak.

1.0 EQUIPMENT

1.1 Sensors:

- There shall be three measurement sensors located across the width of the vehicle a minimum 29" center to center.
- A triggering sensor will continuously sample forward of the measurement sensors for any overhead object. This sensor shall immediately provide for automated triggering of the measurement sensors and data collection when an overhead object is detected. The triggering sensor will also provide for a halt to data collection at a set time after the object has passed. This delay time as well as sampling rate and the number of measurements required to indicate an overhead object will be selectable through software.
- The measurement sensors shall be located a minimum of 7 feet above ground level and secured in a fashion acceptable to the Department.
- Measurement sensors shall be IR laser-diode based (Type IIIb) with a minimum stated accuracy of 0.1 inches and an effective range of 50 feet. They shall have optical power of 20 mW and power input of + 5 volts @ 400 mA.
- Each sensor shall be located within an enclosure that protects it from the weather, has a lid that can be removed or placed in the field, and shades the sensor from all but direct overhead sunlight.
- The measurement sensors shall output calibrated range data in the form of digital data over a serial cable and a 4-20 mA current loop output that is updated once per sample interval and remains constant at that output until a new sample is taken. The current loop output shall be calibrated up to 1 kHz sampling rate.

1.2 Data Acquisition (DAQ) System

1.2.1 Hardware

- The DAQ system shall be computer-based with a keyboard and monitor and utilize the latest version of Microsoft Windows operating system available
- The DAQ system will provide direct serial communication with each sensor.
- Independent power controls for the sensors will be located within the vehicle easily accessible to the operator.
- The DAQ system will read voltages using a type II PCMCIA card with 8 differential or 16 single-ended analog input channels. Each channel shall have a bipolar range of ± 5 volts with programmable gains of 1,2,4 and 8. The PC card shall support sampling rates up to a minimum of 1kHz.
- Current output from the sensor will be read across a 500 (0.1%) ohm resistor in parallel with a 1 MFD capacitor.
- There will be two mechanisms for triggering data collection, manual keystroke and automatic triggering based on a dedicated triggering sensor.

1.2.2 Software

- The user interface will allow selection of either a manual trigger for data collection or the automatic trigger based on input from the trigger sensor.
- The user interface will enable identification of data files that are produced during the manual trigger data collection and configure the software to name files during the automated data collection.
- The format of each data file will be space delimited text file and include the voltage output from each sensor, and the time and date of each sample taken. The time and date fields will be 100% compatible with existing time/date/chainage/GPS information that is collected with existing Department data-collection vans.
- The operating system will allow direct serial communication between the computer and the sensors. This communication will be used to perform troubleshooting, calibration checks, and configuration of the sensors.

2.0 SYSTEM DOCUMENTATION

Upon completion and prior to final acceptance, the Department requires three (3) organized, three (3) ring binders of all manufacturers or vendors literature/specifications of equipment and system components installed. This shall be submitted to the Photolog Supervisor.

Upon completion and prior to final acceptance, the Vendor shall provide drawings detailing the actual installation to the Photolog Supervisor. These drawings shall contain but not be limited to a schematic showing the integration of each component of the device, inputs to and output from each component, and any other particular items as directed by the Photolog Supervisor.

3.0 TESTING

The Vendor shall perform all final checks, sensor alignment, software setup, software installation, and software configuration to ensure the VERMS meets all operational requirements of the contract, and that the complete system is functioning properly.

Before the Department will accept the system, the Vendor must show three (3) days of continuous trouble-free operation sometime between the calendar period beginning month/day/year and ending month/day/year. The Vendor shall submit a test plan in advance for approval by the Photolog Supervisor. The test plan will include provisions to determine the accuracy of the device as installed and demonstrate and calibration procedures that are required. A demonstration of measurement repeatability will also be included in the test plan. The specific three (3) day test period will be mutually agreed upon, in advance,

by the Photolog Supervisor and the Vendor. During this testing period, all equipment, both newly installed VERMS and all other image and data collection modules shall operate without failure of any type. The test shall begin anew each time a failure is identified. It is anticipated that the three (3)-day test will occur immediately following completion of the installation. Official acceptance of the system will be in the form of a written notice from the Photolog Supervisor to the Vendor acknowledging the successful completion of the test plan within the test period. During the three (3)-day test period, no modifications, adjustments or maintenance of the system will be allowed. If any failures are identified, the Vendor shall replace or repair the defective equipment at no additional cost to the State, within 24 hours of notification by the Photolog Supervisor. The Photolog Supervisor shall determine if continuous three (3)-day operation has occurred and the test plan successfully completed.

In the event that VERMS, or part thereof, fails during the three (3)-day test period due to vandalism or an act of God, the Vendor shall restore the equipment to its original operating condition at the Vendor's expense, and a new three (3)-day test period, as described in the previous paragraphs, shall begin on the restored equipment. Payment to the Vendor will reflect the proportion of the system that passes the three (3)-day test period as determined by the Photolog Supervisor in the event that a portion of the system requires a new test.

In the event that the installation, testing, or operation of VERMS damages any other system resident on the photolog van in any way, the vendor is completely and wholly responsible for the repair or replacement of that system or component.

4.0 TRAINING

The Vendor shall provide all training sessions and provide the Department with all manuals and instructional materials for the VERMS as described herein. Thirty (30) days prior to commencing training, the Vendor shall submit course outlines to the Photolog Supervisor.

4.1 Operational Training

One (1) on-site training session, lasting approximately ½ day shall be conducted for photolog technicians at a time and location approved by the Photolog Supervisor. The instructor must have had previous instructional experience and be proficient with the system.

Operational Training shall include but not be limited to: theory of operation, equipment operation, trouble shooting techniques, system/data management, interpretation of data, software usage and maintenance of the system.

The Vendor shall furnish instructional materials for three (3) photolog technicians consisting of a user's manual, which summarizes the system operation and course content of the training session. One (1) additional copy of this material shall be furnished to the Department. Training shall occur after acceptance of the system, so that the equipment may be used as part of the training.

5.0 SERVICE MANUALS

Two (2) copies of Technical Service and Equipment Specification manuals shall be furnished. The manuals shall include and accurately describe service, calibration and testing procedures with module description, circuit diagrams, and detailed schematics, a complete parts list and parts layout, a rack layout drawing indicating the placement of all equipment and cabling, replacement parts lists, installation procedures, mechanical details and termination points for the equipment exactly as furnished, including any equipment that is purchased from other manufacturers.

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6.0 EQUIPMENT WARRANTY

A limited warranty shall be provided covering the replacement of all equipment for a 12-month term after acceptance. The Vendor shall provide full warranty documentation with their shop drawings/catalog cut submissions for evaluating equipment to be installed. A qualified field service engineer in the employment of the Vendor must perform warranty work. All costs associated with the warranty repair are the responsibility of the vendor.

6.1 Warranty Service

Warranty service is considered to be any action and materials required to return the system to normal operating order. The Vendor shall incur all costs for labor, equipment, parts, materials, travel, lodging, and meals while providing warranty service for the period of time described herein.

The initial warranty period will begin the day after the system has received final acceptance by the Department in writing and will last for a period of one (1) year from that date.

For material or equipment malfunction, the Vendor shall provide warranty service within three (3) days or seventy-two (72) hours upon notification by the Department and shall restore the system to normal operating order within five (5) days or 120 hours from when first notified by the Department of the need for such service.

The Vendor during the initial one (1) year warranty period, is required to insure that failure of any part of the system does not result in more than five (5) days or 120 hours of down-time. A performance bond will insure the Vendor to commence warranty service within three (3) days or seventy-two (72) consecutive hours from when first notified by the Department of the need for such service.

The Vendor shall complete all necessary forms to obtain and protect all manufacturer warranties pertinent to the system on behalf of the Department.

All equipment, software, and data furnished shall become the property of the Department. The Department will keep confidential, all proprietary, private or trade secrets, etc.

7.0 SYSTEM MAINTENANCE AGREEMENT

An optional 1, 2 or 3 year Maintenance Agreement shall be available to the Department as a part of this bid. This Maintenance Agreement shall go into effect after the warranty period has expired if the Department chooses to do so.

8.0 EQUIPMENT & SOFTWARE UPGRADES

All equipment and software furnished, including any equipment or software purchased from other manufacturers, shall be new and of the latest design currently in production, and be compatible with existing hardware and user software currently in use in the Department.

The supplier of the proprietary software shall furnish, at no charge to the Department, all upgraded versions of any proprietary software that are released by the vendor for a period of two (2) years from the date of Contract Award. The upgrades shall be sent to the following individual within thirty (30) days from the date they were released by the Vendor.

Department of Transportation
Photolog Supervisor
Street
City, State Zip